



Up Close on



A monthly insert on special topics at Lawrence Livermore National Laboratory. This month: Physics. • • • 2005

Spotlight on Physics at the Laboratory

—William Goldstein
Associate Director for Physics



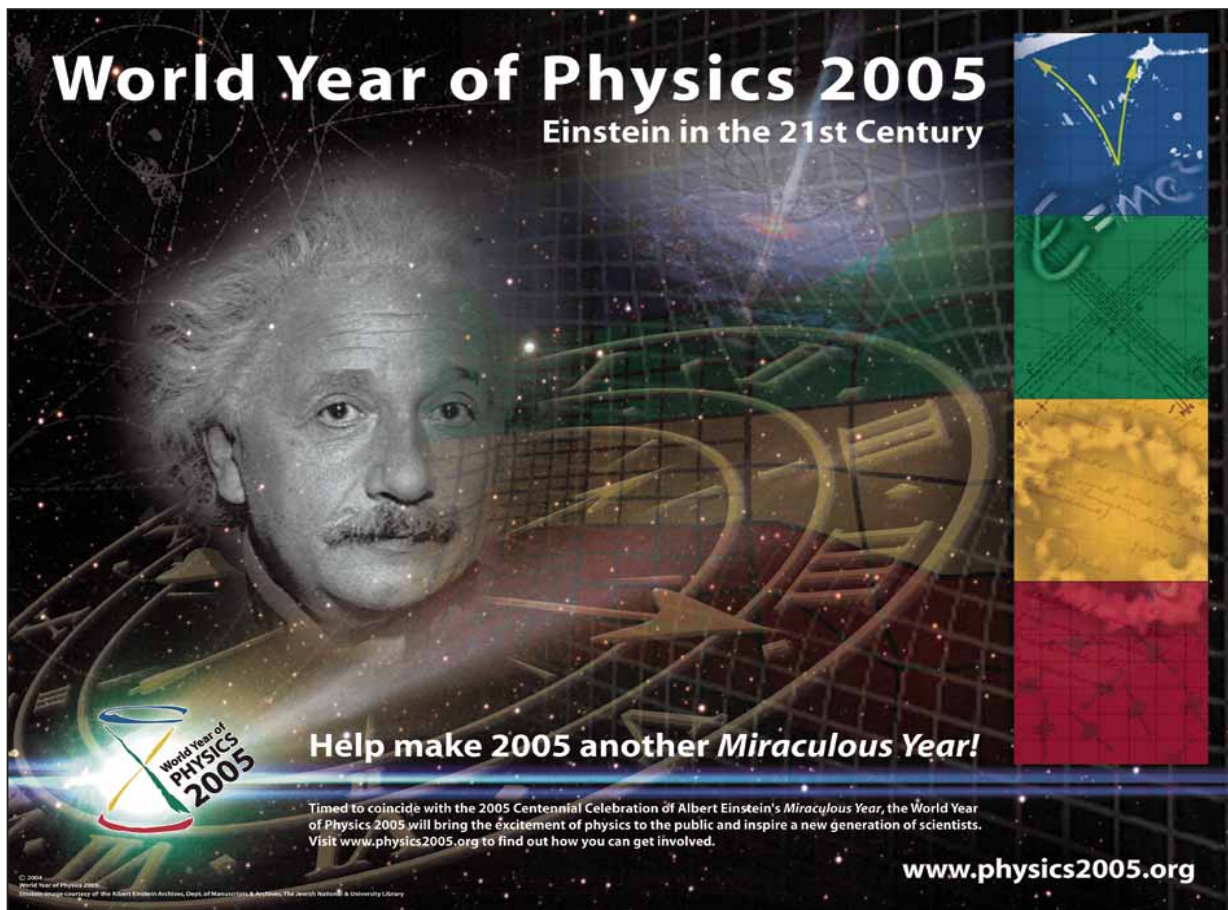
Celebrating the science that created the Laboratory

This year marks the centenary of a watershed in the history of science. In a single year — 1905 — Albert Einstein published papers introducing relativity theory, demonstrating the quantum nature of light and predicting properties of Brownian motion that virtually proved the existence of atoms and molecules. This work presaged the explosion over the past century in our understanding of the laws that govern the universe on scales from sub-atomic to intergalactic. In one year, Einstein set the stage for quantum theory, cosmology and condensed-matter physics.

The transformation of physics wrought by Einstein beginning in 1905 was echoed in 1939 when he played a crucial role in catapulting physics and physicists to the center of world events. Einstein realized then (with a nudge from Leo Szilard) the implications of the recent discovery of nuclear fission, and the fantastic amounts of energy it generated (through the relationship $E=mc^2$). In a famous letter, he alerted Franklin Roosevelt to the possibilities raised by the new research, and the danger of its being exploited by Nazi Germany. He urged Roosevelt to establish contact with the nuclear physicists, and to help speed their work. Edward Teller was Szilard's companion on the trip to Peconic, Long Island, where Einstein's signature was obtained. Einstein's intervention helped initiate the Manhattan Project, and, ultimately, the age of nuclear weapons, in which LLNL has been so significant a player.

From its inception, Livermore has sought to apply modern physics that flowed from the "miracle year" to emerging problems. The first mission of the Lab was to apply nuclear fusion — a process first proposed by Eddington based on Einstein's $E=mc^2$. Livermore became renowned for innovative con-

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Timed to coincide with the 2005 Centennial Celebration of Albert Einstein's Miraculous Year, the World Year of Physics 2005 will bring the excitement of physics to the public and inspire a new generation of scientists.

Physics entwines Laboratory science

Since Lawrence Livermore National Laboratory's founding in 1952, physics has been entwined in all scientific research at the Laboratory.

In scale, physics pervades research from quarks — hypothetically the smallest particle known to man — to stars and galaxies; from femtoseconds — one quadrillionth of a second — to centuries; from a temperature of near absolute zero to nuclear fusion conditions.

Physicists Edward Teller and Ernest O. Lawrence urged Washington leaders to open the Livermore branch of the University of California Radiation Laboratory to more rapidly advance nuclear weapons science and technology. That science and technology would expand beyond weapons work and explore astrophysics, biophysics and medical technologies, lasers and high-energy density physics research, and find applications in homeland security.

Livermore's interest in new small fission weapon designs came to fruition in the 1950s. The research led to some of the Lab's first weapon-development assignments, including the W45 for the Little John and Terrier tactical missile systems and the W48 155-millimeter howitzer atomic projectile. This led eventually in the later 1950s to the development of much smaller diameter H-bomb missile warheads, which made the Polaris submarine program possible and put Livermore on the map.

The first underground nuclear test at the Nevada Test Site led to the idea of using nuclear explosions for non-military uses. The Plowshare Program needed hard data on the effects of such blasts for the program to succeed in exploring peaceful nuclear uses, such as the building of canals and dams.

By the 1960s, the Laboratory was exploring non-nuclear testing capabilities. At Site 300, a linear accelerator (linac) generated powerful X-ray flashes need-

ed for taking images of mock nuclear-weapon primaries as they imploded. During this decade, the Laboratory proof-tested nuclear designs and laid the groundwork for future Livermore designs of compact high-yield ballistic missile warheads. The bioscience and environmental programs were spawned as a way scientists could begin to understand the consequences of atmospheric nuclear testing. Follow-on biotechnology developments contributed to the Department of Energy's decision to launch its Human Genome Initiative.

Beginning in the 1970s, the Lab began its world-renowned laser program and has remained at the forefront of laser science and technology ever since. In 1973, the Uranium Atomic Vapor Laser Isotope Separation (U-AVLIS) program began to help maintain the U.S. market share of enriched uranium fuel for nuclear power plants. But it was the development of Janus that started the first of a sequence of ever-larger lasers to explore inertial confinement fusion (ICF) for national security and civilian applications. The energy crisis of the 1970s helped invigorate long-term research into ICF and magnetic fusion as alternate sources of energy.

The 1980s saw the ever-increasing combination of experiments and computer simulations to develop new strategic weapons, such as a nuclear bomb that could be delivered at low altitude. Lasers continued to be a major focus in the 1980s with the Nova laser enabling further research in X-ray lasers. At the time, Nova was the world's most powerful laser. The 1980s also saw the publication of Robert Laughlin's theoretical work explaining the so-called fractional quantum Hall effect in *Physical Review Letters*. The work later led to Laughlin earning a Nobel Prize in 1998.

What is physics?

Physics is the science of matter, energy, space and time. It is all around us — in the lights we turn on, the cell phones we use, in the stars that shine and the wind that blows.

Getting "Up Close" with science

Editor's note: This month's "Up Close" focuses on the World Year of Physics 2005, a United Nations endorsed, international celebration of physics. It commemorates the pioneering contributions of Albert Einstein in 1905 and brings the excitement of physics to the public to inspire future generations of scientists. ✪

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Groundbreaking science appears as cover story in scientific journals

During the past 18 months, Livermore scientists delving into high-impact areas of physics have been the cover story on six different scientific journals. The groundbreaking work varies from finding a new state of matter, to characterizing interstellar dust particles to better anthrax detection methods.

National Geographic

Most recently, the December 2004 *National Geographic* cover story, “Search for other Earths,” featured Laboratory physicist Bruce Macintosh’s work searching for planets orbiting other stars.

The next major step in this area will be direct detection — actual images of the extremely faint planets next to the extremely bright stars. The stars will be surrounded by a halo of light scattered by the Earth’s atmosphere, imperfect optics, and fundamental processes such as diffraction. Current ground-based telescopes — even with adaptive optics — and the Hubble Space Telescope could only see a planet if the parent star is very dim or the planet very young and bright.

Macintosh is leading a multinational team (including UC Berkeley, UC Santa Cruz, UCLA, JPL, the American Museum of Natural History and the Herzberg Institute of Astrophysics and University of Montreal in Canada) that is designing a next-generation system to systematically study planets in solar systems like our own for the US/UK/Canadian Gemini telescope. If built, this “extreme” adaptive optics system would be the world’s most advanced, with an order of magnitude more powerful than current systems, with nanometer-level control of the wave front and meticulous shaping of scattered light. The system could be operational by 2009 and capable of discovering and characterizing more than 100 giant planets orbiting nearby stars, providing new insights into the nature of other solar systems.

Nature

Stanimir Bonev, Eric Schwegler, Tadashi Ogitsu and Giulia Galli predicted a new melt curve of hydrogen, indicating the possible existence of a novel quantum fluid of liquid metallic hydrogen.

The work was featured on the cover of the Oct. 7, 2004 edition of the journal *Nature*.



The researchers presented the results of ab initio calculations of the hydrogen melt curve at pressures up to 2 million atmospheres.

The measurement of the high-pressure phases of hydrogen has been the focus of numerous experiments for nearly a century. However, the phase boundary that separates the solid

and the liquid has remained relatively unknown. Until now, when Livermore scientists reported the melt line with first principles simulations, and proposed new experimental measurements to verify the existence of a maximum melting temperature and the transformation of solid molecular hydrogen to a metallic liquid at pressures close to 4 million atmospheres.

Meteoritics & Planetary Science

The cover article on the September 2004 issue of *Meteoritics & Planetary Science* features a joint project between the Laboratory’s Center for Accelerator Mass Spectrometry (CAMS) and the Institute for Geophysics and Planetary Physics, in which a CAMS nuclear microprobe was used to characterize

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Shocking experiments lead to scientific discovery

It’s a realm where a “bore” can generate excitement. A “spike” could mean plutonium 238. And a gun becomes a scientific instrument. Welcome to the physics of stockpile stewardship: condensed-matter and shock physics.

Stockpile Stewardship is the National Nuclear Security Administration (NNSA) program to ensure the safety and reliability of the nation’s nuclear deterrent. Under this program surrogate scientific experiments and computer simulation replace underground testing of nuclear devices in the Nevada desert.

Condensed-matter physics has resided at the core of the Laboratory research since its founding. Longtime Livermore employee Robert Laughlin received the Nobel Prize for Physics for condensed-matter work in December 1998.

Plutonium’s complex electronic structure remains a most challenging problem in condensed-matter theory. When heated from room temperature and pressure to approximately 600 degrees Celsius, plutonium experiences four phase changes. The volume, crystal structure and thermal expansion also vary from one phase to another. Condensed-matter research provides scientific insight into those phase changes, and also allows aging studies on plutonium and weapon components using Pu238 spikes.

Shock physics researchers study the behavior of materials as a shock wave passes through them. The shock can be generated by high explosive detonation or by a high-speed projectile propelled down a gun “bore” to impact a target.

Shock physics is essential to stockpile stewardship. In thermonuclear weapons, X-ray radiation from a fission explosive can be contained and used to transfer energy to compress and ignite a physically separate component containing thermonuclear fuel.

Hydrotests measure the implosion characteristics of primary systems. Hydros are named for the fluid-like behavior of metals under these conditions.



The Laboratory’s design for the W47 Polaris warhead made it practical for U.S. nuclear deterrent forces to be deployed from highly survivable submarines.

Hydrotests and other shock experiments are conducted at the High Explosives Application Facility (HEAF), the Contained Firing Facility (CFF) at Site 300 and facilities at the Nevada Test Site including the Big Explosives Experimental Facility (BEEF), the JASPER gas gun and the U1a underground facility for conducting “subcritical” explosive shock tests on nuclear materials.

B Division leader Charles McMillan explain: “Much of our weapons simulation codes derive from hydrodynamic tests. Mock weapon primaries, with surrogate nuclear materials, are blown up before powerful flash X-ray machines. They allow scientists to ‘see’ inside imploding assemblies and capture the dynamics of materials in motion at ultra-high speeds. HEAF, CFF, BEEF, JASPER and U1a are our principal laboratories for shock physics experiments.”



Experiments to determine the equation of state of plutonium began in 2004 on the Joint Actinide Shock Physics Experimental Research (JASPER) two-stage gas gun at the Nevada Test Site. JASPER is used to determine the properties of plutonium at high temperatures, pressures, and strain rates by shocking the material, then measuring the response.

Weapons science and the Big Bang

It seems unlikely that a nuclear weapons laboratory would have much interest in the creation of the universe.

But the basic sciences of nuclear weapons and astrophysics are integrally linked. Out of this common science base, astrophysics emerged as an important discipline at the Laboratory.

“Exploding stars are analogous to the explosions of nuclear weapons,” said Bruce Tarter, Lab director emeritus. “X-rays and gamma rays that occur in space are similar to complicated things that happen in the atmosphere after a bomb explodes.”

Tarter, who majored in astrophysics, said that when he finished grad school in the early ‘60s, it was an exciting time in his field. Lab physicists had produced two of the most important papers in astrophysics at the time. Using some early supercomputers, Stirling Colgate and Dick White wrote a paper describing why stars explode and former Lab director Mike May and White wrote a follow-up paper about why stars implode to become black holes.

Tarter said many physicists who worked in the weapons program did astrophysics “on our own time.”

By the 1970s, the University of California urged the Lab to open a branch of the Institute for Geophysics and Planetary Physics (IGPP), a UC multi-campus research unit. Other branches are at UC Los Angeles, UC San Diego, UC Riverside, UC Santa Cruz and Los Alamos National Laboratory.

Claire Max was recruited from the laser-plasma interaction group in the Inertial Confinement Fusion program to be the first director of Livermore’s IGPP. Max is currently director of the Center for Adaptive Optics, Science and Technology Center with headquarters at UC Santa Cruz, and she maintains her association with IGPP. Max is responsible for the Laser Guidestar Project, which aims to improve the performance of ground-based astronomical telescopes by correcting for the blurring of astronomical images caused by turbulence in the atmosphere. Using lasers, optics, and systems engineering expertise from the Laboratory’s laser program in combination with IGPP’s astrophysics expertise, this project is developing technology that allows large Earth-bound telescopes such as UC’s Lick Observatory (California) and the Keck Telescope (Hawaii) to achieve their full scientific potential.

Another pivotal point in the astrophysics program occurred when Charles Alcock joined the Laboratory. While at the Lab, Alcock headed the U.S. project to search for massive compact halo objects (MACHO) and estimate their contribution to the dark matter component of the Milky Way’s halo. The MACHO project continues at the Laboratory. Alcock is now director of the Harvard-Smithsonian Center for Astrophysics, director of the Smithsonian Astrophysical Observatory, director of the Harvard College Observatory and professor of astronomy at Harvard University.

More recently, John Bradley arrived at the Laboratory to serve as IGPP director. Bradley is heavily involved in the Stardust mission that will collect exotic samples from the sun, a comet and an asteroid. The IGPP is currently preparing for the return of the Stardust spacecraft.

The Stardust mission launched in February 1999 is the first U.S. “solid matter” sample return mission since Apollo 17 in 1973. Aerogel collectors on Stardust have already been deployed for interstellar dust collection. The samples will be returned to Earth in early 2006. IGPP researchers are exploring particle extraction and analysis techniques that will maximize



Livermore researchers installed an adaptive optics system to create a laser guidestar on the Keck telescope in Hawaii.

the scientific return of these unique particles.

The upcoming Large Synoptic Survey Telescope (LSST), set to be built in Chile, Mexico or the Canary Islands, is bound to be a boon for astrophysics at the Laboratory. The LSST is a proposed ground-based telescope that will be able to survey the entire visible sky every three nights on objects that change or move on rapid timescales — exploding supernovae, Earth-approaching asteroids and distant Kuiper Belt objects. The Laboratory’s Kem Cook, who previously worked on the MACHO project, will be heading the astrophysics side of the telescope while Lab physicist Don Sweeney serves as LSST project manager, handling the engineering side of the project. Stanford, the Stanford Linear Accelerator Center (SLAC) and UC Davis are also playing crucial roles in the LSST.

Robert Becker, who also is a physics professor at UC Davis, heads the IGPP’s Astrophysics Research Center, which includes managing the astrophysics part of the University Collaborative Research Program (UCRP) and facilitating contacts between UC scientists and their LLNL counterparts. It serves as the focus of Lab astrophysics activities by organizing the weekly astrophysics colloquium, hosting visitors and collaborators and editing an annual “Observatory Report” that covers all astrophysics activities at LLNL (and is published in the *Bulletin of the American Astronomical Society*).

Other astrophysics projects at IGPP are galaxies and quasar research in the formation and evolution of galaxies, clusters of galaxies and active galactic nuclei (including quasars); Faint Images of the Radio Sky at Twenty centimeters (FIRST), a project designed to produce the radio equivalent of the Palomar Observatory Sky Survey over 10,000 square degrees of the North Galactic Cap; and the Taiwanese American Occultation Survey (TAOS) that will probe the Kuiper Belt region of the solar system for objects as small as 2 kilometers using an occultation technique that the Lab pioneered. Further, high energy astrophysics work is also being conducted by Bill Craig’s and Simon Labov’s groups.

“Astrophysics is a natural match for the Lab,” Tarter said. “Out of the nuclear weapons program, good science emerged to help nurture other Lab programs.”

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interstellar dust particles as part of the Stardust Project.

The Stardust spacecraft will return to Earth in 2006 with cometary and interstellar dust particles embedded in silica aerogel collectors.

Working with Imperial College in London, the Spaces Sciences Laboratory at UC Berkeley and the Natural History Museum in London, CAMS researcher Patrick Grant was able to characterize analog particles implanted in silica aerogel with a nuclear microprobe.

“The CAMS research was pivotal in this work,” said John Bradley, IGPP director. “This analysis hadn’t been done before with this material and they proved it was capable.”



Physical Review Letters

In spring 2004, Kevin Fournier worked with the Nonproliferation, Arms Control and International Security Directorate and

the Inertial Confinement Fusion program to develop a technique to introduce a heavy element in a low-density aerogel foam that earned them the cover of the April 23 edition of *Physical Review Letters*.

Using an aerogel target with three-atom percent titanium, the Livermore team used the OMEGA laser at the University of Rochester to shoot the target. The titanium within the target converted the blue laser light into 4.7 kilo electron volt X-rays. Because the density of the aerogel material that held the Ti dopant is so low, the laser does not see a solid target (an inefficient converter), but instead sees a solid that looks like a gas (a good converter).

The researchers plan to continue their work this March with a new process that can introduce six times the amount of even heavier elements embedded in the aerogel.

Analytical Chemistry

In October 2003, Livermore physicists made history again by garnering the cover of *Analytical Chemistry* with the development and testing of the Autonomous Pathogen Detection System (APDS).

Researchers Mary McBride, Don Masquelier, Benjamin Hindson, Anthony Makarewicz, Steve Brown, Keith Burris, Thomas Metz, Richard Langlois, Kodumudi Vankateswaran, Fred Milanovich and Bill Colston were part of a team that built the APDS, a system that is capable of continuously monitoring the environment for airborne biological agents as an early warning system for civilians in the event of a terrorist attack.

The system was tested in a Biosafety Level 3 facility, where it detected a series of aerosolized released containing two live, virulent biological threat agents, *Bacillus anthracis* (anthrax) and *Yersinia pestis* (plague).

The system was built in response to the anthrax attacks of 2001. The APDS was recognized as one of the top 100 inventions, and in 2004, the Lab received an R&D100 Award.



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Physics milestones at LLNL

Over the course of the past 50 years, Laboratory scientists and programs have achieved breakthroughs in physics that build on the work of Albert Einstein and the quantum generation he spawned. Following are some physics highlights from five decades of basic science and national security research.

1952

1953

1954



The Livermore branch of the University of California Radiation Laboratory at Berkeley opens for operation on Sept. 2.



Ruth, the Laboratory's first nuclear test, provided information about certain thermonuclear reactions, although it fizzled.



Focus on fusion: Research energizes

Ever since 1960, when physicists Charles Townes and Arthur L. Schawlow of Bell Labs received the first patent for "Light Amplification by Stimulated Emission of Radiation," the Lab has been engaged in the study and use of lasers.

And for much of that time, LLNL has been home to the largest lasers in the world.

The Lab's first laser fusion project, built in 1962, resulted from research by a group of physicists who were studying how to use powerful, short laser pulses to compress and ignite a small amount of deuterium-tritium fuel.

That same year, Lab director Johnny Foster, former director Edward Teller, and Physics leader Ted Merkle decided to start a laser development and weapons physics project. Even though the lasers of the '60s were miniscule by today's stan-

dards, the Lab started evaluating the construction of high-power lasers and laser-driven implosion schemes. The most noteworthy system in those years was named Long Path, LLNL's first neodymium-doped glass disk and multi-pass laser. Neodymium is a bright, silvery rare-earth metal used as the active lasing element.

Beginning in 1972, Livermore scientists designed, built and operated a series of increasingly energetic and powerful solid-state systems. It all started with the "4 pi" system and continued with Janus, Cyclops, the two-beam Argus, the 20-beam Shiva, the two beams of Novette, the 10-beam Nova,



Inside the Nova

1983

1984

1994

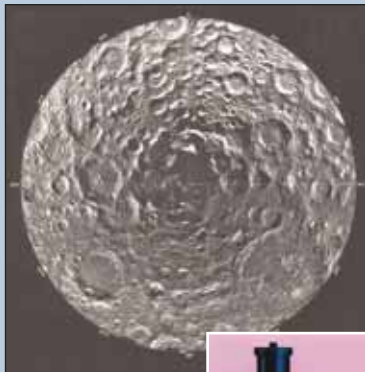
1995



Robert Laughlin's theoretical work explaining the so-called fractional quantum Hall effect is published in *Physical Review Letters*. The work later led to Laughlin earning a Nobel Prize in 1998.



The Nova laser becomes operational, enabling further research in X-ray lasers. At the time, Nova was the world's most powerful laser.



Six on-board cameras designed and built at the Laboratory for the Clementine satellite map the entire surface of the moon at resolutions never before attained.



The Clementine satellite's mission was to map the moon's surface at resolutions never before attained.

1957 1960 1963 1970



The Laboratory detonated the first contained underground nuclear explosion (Rainier) at the Nevada Test Site

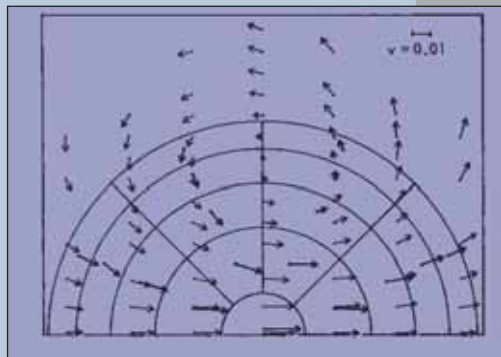


A new linear accelerator that generates X-ray

flashes for taking images of mock nuclear-weapon primaries as they implode is delivered to Site 300.



The first biomedical and environmental research program begins at Livermore to determine the biological consequences of fallout radiation.



From early molecular dynamic simulations, Lab researchers find evidence of hydrodynamics applied on an atomic scale.

zed Lab development of lasers



a laser chamber.

Petawatt and Beamlet.

And now, the National Ignition Facility continues that proud tradition. When the last of its 192 beams is installed in 2008, NIF will offer unique capabilities, including the most energy of any laser facility in the world.

With its ability to provide a variety of laser pulse shapes and lengths, NIF also will offer more power and far more energy than any other laser facility.

“The National Ignition Facility will be about 20 times more powerful

than the Nova laser and will deliver about 60 times more energy,” said John Lindl, Livermore’s scientific director for inertial confinement fusion.

When Nova operated with ultraviolet light, it produced 30 kilojoules of energy and 25 terawatts of power. In contrast, the 192-beam NIF will generate 1.8 megajoules and 500 terawatts.

LLNL technology has had a major impact on the development of other large glass laser facilities in the United States, including the Omega laser and more recently the Omega EP (Extended Performance) at the University of Rochester in New York and the Beamlet laser (originally the NIF scientific prototype) now at Sandia National Laboratory in Albuquerque, NM. Lasers in Japan, France, the United Kingdom, Germany and other countries around the world also use LLNL technology.

5 1960 1997 1999

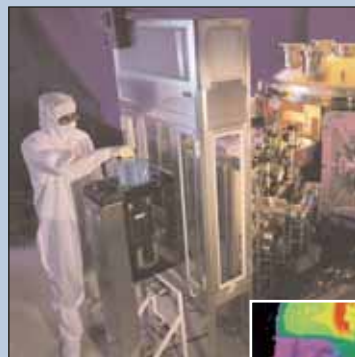
Lab participates in search for elusive comets (CHO) to make their distribution the dark matter component of the Milky Way’s



The first laser guidestar is installed at the Lick Observatory. The 15-watt dye laser system, an outgrowth of the AVLIS program, was retrofitted onto the Shane telescope. Laboratory researchers succeed in achieving a long-sought goal of high-pressure physics — converting hydrogen to a metal.



The stadium-sized 192-beam National Ignition Facility breaks ground. With four beams in operation, it is the world’s most energetic infrared laser.



Livermore scientists develop PEREGRINE, a new tool for helping doctors plan cancer radiation treatment on a patient-specific basis, and license it to NOMOS Corporation. Extreme Ultraviolet Lithography (EUVL) is developed in conjunction with Sandia, LBNL and industry to extend the current pace of semiconductor innovation. Both technologies earned an R&D 100 award.

Science minds at work throughout the Lab

Bruce Tarter
Former Laboratory director

I first became interested in astronomy and physics around the ages of 8 and 9 when I checked out a book on cosmology and astronomy entitled, "One, Two, Three... Infinity," by George Gamow. A couple of years later I read everything I could find by Fred Hoyle, things like the "Nature of the Universe," and I was completely taken with math and astronomy from that time on. Fortunately, those interests coincided with aptitude, and I continued to read things like, "The World of Mathematics," a treasure chest of stories and puzzles and articles in four giant volumes, as I went through junior high.

By high school it was clear that physics was the basis for all of that and so I was very focused on doing some combination of math, physics and astronomy as my life's work. (This is pretty much the way a musician does it, you don't 'pick a career,' you just do what you like doing and hope it works out.) I was always of the theory and math persuasion, not the experiments and "take things apart" group, which made it pretty easy to pursue all my interests.



Regina Soufli
I Division/Physics and Advanced Technologies

After completing my undergraduate education with a major in electrical engineering in my hometown of Athens, Greece, I was accepted by the graduate program at UC Berkeley. My first

encounter with the field of X-ray optics occurred in the spring 1993. From that course I learned how X-rays can be implemented as a tool for exciting science: through the interaction of X-rays with matter one can probe the properties of the innermost electronic shells of any atom, or image samples with nanometer-scale resolution; X-ray radiation emitted from celestial objects can provide clues to the unraveling of important astronomy questions such as the origins of the universe.

Looking back to that introductory X-ray optics course I took in 1993, I feel very fortunate to have contributed to such exciting high-energy science and technology applications that were enabled by developing state-of-the-art X-ray optics. In addition to my own hard work, for this success I credit those individuals I have worked with throughout my career, who were outstanding colleagues and mentors and instilled in me lifelong inspiration and commitment to research.

William Evans
H Division/Physics and Advanced Technologies

As a physicist I can think of numerous reasons for choosing a career in physics: understanding nature at a fundamental level; developing techniques to address urgent technological needs and contributing knowledge to improve the quality of life for



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Pursuing the promise of fusion energy

For more than half a century, scientists at Livermore and around the world have been working to solve one of the most difficult — and potentially most important — problems in all of physics.

The problem: how to harness nuclear fusion, the process that powers the sun and stars as well as thermonuclear weapons, to provide future generations with an unlimited source of energy.

LLNL's fusion research has taken a variety of approaches to generating energy by fusing atoms of hydrogen — a resource that, unlike fossil fuels or the uranium and thorium needed for current nuclear fission reactors — is virtually inexhaustible.

The goal of fusion energy is to apply enough heat and pressure on a plasma — an energetic soup of electrons and positively charged hydrogen ions — to force the hydrogen nuclei to fuse, releasing far more energy than the amount required to heat the plasma. The basic barrier to success has been plasma's turbulence and instability: thermal and pressure fluctuations in the plasma's superheated core keep it from reaching the heat and pressure needed for fusion.

Livermore's early fusion research focused on the use of magnetic "mirrors" to contain the plasma in cylindrical magnetic fields, pinched at their ends like a party popper. Although the Lab made progress in measuring and understanding the behavior of plasmas, its work on mirror-confined plasma eventually took a back seat to doughnut-shaped "closed" reactors, known as tokamaks.

The next big step for tokamak research is the construction of the International Tokamak Experimental Reactor (ITER), a 10-year, \$8 billion research project that scientists believe will achieve the Holy Grail of fusion research: producing more energy than it consumes.

LLNL is supporting the ITER project by developing diagnostic tools to determine the strength of the reactor's internal magnetic fields. In addition, theorists will use the Lab's supercomputers to develop sophisticated models of tokamak plasma behavior, enabling plasma physicists to simulate ITER's opera-



One of the yin-yang magnets for Magnetic Fusion Test Facility-B (MFTF-B). The magnet system for MFTF-B was the largest superconducting system ever built.

tion and achieve a comprehensive understanding of how the reactor's components will work together.

The Lab also is pursuing several other approaches to fusion that could turn out to be more economically attractive for commercial energy production than the expensive, warehouse-sized tokamaks:

- Fusion pioneer Dick Post and his colleagues in the Lab's Magnetic Fusion Energy Program continue to explore new techniques for containing plasma in magnetic mirror systems, which are inherently less turbulent than tokamaks.

- The Lab's Sustained Spheromak Physics Experiment, dedicated in 1999, could lead to a simpler, more compact and less expensive fusion reactor than the tokamak. Instead of giant electromagnets, the spheromak uses currents flowing in the plasma to generate the magnetic fields — creating, in essence, a self-confined plasma.

- The National Ignition Facility (NIF), the world's most powerful laser facility, is being built to demonstrate a process called inertial confinement fusion, which generates vast amounts of energy. NIF will focus 192 laser beams on a BB-size capsule of hydrogen fuel, causing the capsule to implode and create fusion ignition and burn. The process would release about 10 times more energy than was used to drive the implosion.

"Fusion is a very attractive alternative to fossil fuels and fission," said LLNL physicist David Hill. "That's what powers most of us in this field. We can make a large contribution to society if we can bring this to fruition."



Note: For a highly readable account of the colorful history of fusion research through the 1980s, see "Fusion: The Search for Endless Energy" by Robin Herman (Cambridge University Press, 1990), available at the LLNL Library.

The first Livermore laser for Inertial Confinement Fusion research, Janus, had two beams and produced 10 joules of energy.

Radiation science for national defense

To protect the United States against terrorists, LLNL physicists and other national labs have developed some of the most advanced radiological detection instruments.

“We’re focused in homeland security on finding the radiological signatures from nuclear materials against a highly variable background of natural and unnatural but benign sources of radioactivity,” said Simon Labov, director of the Lab’s Radiation Detection Center.

It is a complex problem in Labov’s view. For example, a radiation detector that moves near a granite building may see a two-fold signal increase, but the signal would drop if a truck blocks the detector from the building. Then the signal could skyrocket if a person passes by who has had a medical treatment with radioactive tracers.

“How do we tell the difference between a truck carrying a nuclear weapon and a truck loaded with kitty litter?” Labov asks. He answers that two critical physics tools help distinguish between the two types of radioactive sources.

One is gamma ray spectroscopy, which assists in understanding nuclear processes. Spectrometers used in nuclear physics can distinguish between different radioactive isotopes and can help inspectors rule out threats from such benign radioactive sources as medical patients.

The second tool is gamma ray imaging, which can be used to locate and measure highly energetic astrophysical phenomena. These imagers are now



Klaus Ziock (left) and Lorenzo Fabris prepare the large-area gamma-ray imager for field testing. The instrument uses about half a square meter of gamma-ray detectors behind a one-dimensional coded aperture mask (gray bars in photo) to search for compact sources of radioactivity.

being used to distinguish between radioactive sources that could be a threat and those associated with natural background, building materials or common cargo.

The Laboratory, as well as CalTech, the Harvard Smithsonian Center for Astrophysics, UC Santa Cruz and other organizations, are contributing to the development of a large gamma ray satellite that will use coded aperture imaging techniques to measure black holes in space.

On Earth, the same techniques are able to detect weak signals from nuclear materials at much larger distances than was previously possible, according to Labov.

The Laboratory, he notes, has many physics research efforts in nuclear physics, particle physics, high-energy physics and astrophysics that use advanced detection technologies. Many of these same technologies are being leveraged for homeland security and nonproliferation applications.

Lasers find medical applications fighting disease

As the Year of Physics is celebrated, Albert Einstein’s explanation of stimulated emission in a 1917 publication led to the invention of the laser almost 40 years later. Today, lasers are widely used in medicine and many other fields.

At LLNL, lasers are being used in the Medical Technology Program (within M Division) to assist physicians in treating many medical problems, ranging from cancer to strokes to diabetes, notes Steve Lane, deputy leader for M Division.

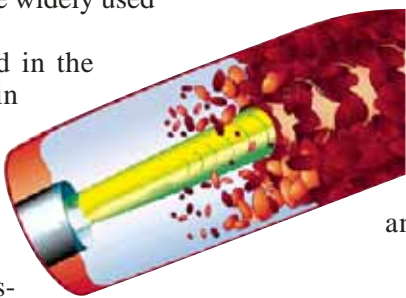
Physicist Stavros Demos is investigating using lasers to characterize tissue by shining light onto the tissue in order to analyze the light reflected back. Optical signatures can then help to tell the difference between cancerous and non-cancerous tissue. This work, which could permit the detection of bladder cancer without a surgical biopsy, is being undertaken in collaboration with UC Davis Cancer Center researchers.

Since November 2000, about 200 researchers from the Laboratory and the UC Davis Cancer Center have collaborated on various medical projects in lasers, physics and other areas as part of an integrated cancer program.

In another joint project, researchers Thomas Huser and James Chan at LLNL are collaborating with physicians Doug Taylor and Ted Zwerdling at UC Davis. They are using lasers to trap single cells in a technique called laser raman spectroscopy that uses scattered light to indicate what constituents are in the cell, and may also differentiate between cancerous and non-cancerous cells.

Livermore researchers have developed a small device known as an Endovascular Photo Acoustic Recanalization to assist in combating strokes. This device uses a catheter to guide a fiber optic cable to the site of a blood clot in the brain and then uses

laser light to destroy the clot. The technology has been licensed to a company and has been tested in human trials.



The technique used to break cerebral clots consists of converting laser energy to acoustic stress waves. The challenge is to break up the clot without damaging the blood vessel.

Duncan Maitland, leader for the Medical Technology Program, is directing a team of 30 investigators at LLNL, UC Davis, UC San Francisco and UC Berkeley in designing therapeutic devices and developing analytical and computational techniques to help understand interactions between the devices and the human body. The technology uses laser-heated shape

memory polymer microactuators that can be applied to diseases like treating stroke and preventing heart attacks.

A Livermore technology known as PEREGRINE is a revolutionary computer simulation tool for analyzing and planning radiation treatment for cancer patients. While current dose calculation methods approximate the radiation dose distribution in the patient based on dose distributions in water, the PEREGRINE system accurately predicts radiation doses to tumors during radiation therapy planning by using realistic models of the patient and accurate X-ray transport parameters. It is currently in use by the medical community.

In 1921, Einstein won a Nobel Prize for explaining the photoelectric effect. Interestingly enough, this process is a key ingredient in the PEREGRINE system that is in use in the 21st century.

Physicists

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mankind. I chose physics for two reasons, one practical and the other selfish. I wanted to understand things from the bottom up, and I wanted a peek at what sits just over the scientific and technological horizon. For example, transistors led to microprocessors and our modern day computers, Roentgen’s X-rays now elucidate crystal structures and the ubiquitous double helix of DNA. A glimpse at nature’s rulebook and a good measure of imagination are a scientist’s crystal ball.

I was exposed to scientific, analytical and orderly thinking from birth. My father was a chemistry professor and my mother was a librarian. As a high school student I pursued chemistry, but quickly shifted to physics in college. I cannot point to a single event that caused this shift, but physics was a very competitive major and physicists had a strong presence and influence on campus. My background in physics now colors my perception and approach to problem solving. As our understanding of nature and technology advances, all scientists are adapting increasingly cross-disciplinary perspectives. However, the physicists’ first-principles bottom-up approach, building up from sub-atomic particles, is most appealing to me. This complements the contrasting atomic-molecular-macromolecular perspectives of sister sciences such as chemistry and biology. These varied perspectives are all valuable and important, combining to form a more complete picture of all facets of science.

Jutta Escher

N Division/Physics and Advanced Technologies

Instead of making us add simple numbers, my first-grade mathematics teacher let his students play with colorful shapes and taught us what I now know to be the very basics of the mathematical field of Set Theory. Back then, however, our parents were surprised, some were even alarmed — I loved it! Eventually, I did learn how to add and subtract, but I have always been fascinated by the abstract world of mathematics.

In high school in my native Germany, I majored in mathematics and physics. I had wonderful teachers who knew their fields well, showed enthusiasm for the subject matter and enjoyed challenging their students. I discovered that the language of mathematics plays a central role in describing physical phenomena and in formulating hypotheses and theories.

In college, I increasingly found myself marveling at the beauties, simplicities and symmetries that the world of physics revealed. My studies have taught me not only facts and figures, but a whole way of thinking about, reflecting on and exploring the world around me, both inside the field and in life at large. That considered way of “doing life” has been a wonderful gift.

Tamara E. Jernigan Physics and Advanced Technologies/AD Office

As a child I always enjoyed science and math, however my specific interest in physics developed in high school after I studied physics and then became a teaching assistant for the class. I found it quite interesting that one could derive from very basic principles an equation of motion and that equation could be experimentally verified in the laboratory. I was also fascinated by both the theory of special relativity and the fact that this unique concept could actually be tested. I viewed physics as elegant and powerful and decided then to pursue this predictive science in college.



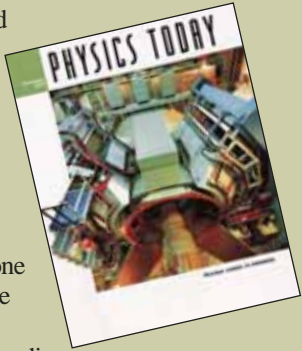
Journals

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Physics Today

The *Physics Today* cover article from the October 2003 issue prominently displays the LLNL-designed magnet for the PHENIX experiment at the Relativistic Heavy Ion Collider (RHIC).

For the past five years, the RHIC at Brookhaven National Laboratory has been colliding fully stripped gold (Au) ions into one another at 99.995 percent the speed of light with the goal of recreating a state of matter (Quark-Gluon Plasma (QGP)) that may have existed at one micro-second after the big bang.



To create the conditions for a QGP inside the collisions, temperatures of roughly 1 trillion degrees must be attained. However, like cosmologists studying the big bang, physicists don't get to peer inside the collisions. Instead, physicists at RHIC must reconstruct what happened from the distribution of particles that exist in the aftermath.

Scientists at LLNL have been actively involved in attempting to recreate the QGP since the 1980s, beginning with the work of Chip Britt, Jim Thomas and Craig Sangster. However, the field has recently entered a new era with the commissioning of RHIC. Livermore has been heavily involved from the start, contributing to the design of the magnets for the one of the two large experiments at RHIC known as PHENIX. The green magnets that are featured prominently on the *Physics Today* cover play a central role in bending the paths of charged particles produced in the collisions so that physicists can identify them and measure their momenta. This quest continues under the guidance of Ron Soltz and Ed Hartouni with the goal of observing the QGP and learning something fundamental about the interactions of quarks and gluons.

History

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Astrophysics soared in the 1990s. First with the Clementine satellite mission, where six on-board cameras designed and built at the Laboratory were used to map the entire surface of the moon at resolutions never before attained. Then in 1996, the first laser guidestar was installed at the Lick Observatory. The 15-watt dye laser system, an outgrowth of the AVLIS program, was retrofitted onto the Shane telescope. The guidestar and the adaptive optics system are today being installed on some of the largest telescopes in the world. Lasers grew even larger, when the stadium-sized 192-beam

Spotlight

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cepts in both military and civilian applications of nuclear fusion, culminating with the portentous proposal of inertial confinement fusion by Lowell Wood and John Nuckolls.

To understand and model the extreme conditions that lead to nuclear fusion, the Lab applied the newest and most powerful computers, and became a leader in "multi-physics" computer simulation codes. The combination at LLNL of world-class physicists, and the world's most powerful computers, led to some of the Lab's most important scientific contributions: the discovery by Berni Alder and Tom Wainwright of the 2-D melting phase-transition using molecular dynamics simulations; the explanation by Stan Woosley, Tom Weaver and George Zimmerman of type II supernovae; and the first results of relativistic gravitational hydrodynamics by Jim Wilson. It's possible in these "multi-physics" problems to catch glimpses of the novel combination of atomic kinetic theory with hydrodynamics

Events celebrate World Year of Physics

This year, while the international science community commemorates the importance of physics and the works of Albert Einstein, the Laboratory will join in the celebration by hosting a number of events for employees, community members and local students.

A variety of lectures, interactive demonstrations and hands-on experiments for school chil-

dren, special exhibits and guest lectures for the public, as well as a weeklong celebration of physics for the scientific world, community leaders and physics students are planned.

Below is a preliminary list of upcoming events by month. Look for details on the Lab Website and in upcoming weekly issues of *Newsline* and *Newsonline*.

February

The Lab's school tour program for local elementary students will incorporate additional physics-related facts and experiments in the Fun with Science portion.

Feb. 5 — The Lab will kick off the 2005 Science on Saturday lectures with the talk "Juggling the Power of Light: How Lasers Work." (The lectures will occur on five consecutive Saturdays through March 5.)

Feb. 18-21 — Lab employees will participate in the AAAS conference where the DOE will exhibit a "Year of Physics" display.

March

Cable channel 30's "Technology Today" will broadcast a program highlighting the Lab's role in physics and the life and times of

Albert Einstein.

The Director's Distinguished Lecture Series will present a physics speaker.

April

A "Year of Physics" poster will be on display at the Livermore Public Library.

Community lectures will be presented on the "Top 10 Physics Events."

May

A banner will be placed above 4th Street in Livermore announcing "LLNL Celebrates the World Year of Physics."

May 6 — A "World Physics Day" will take place at Marine World.

May 23 — The "Week of Physics" at the Lab will take place on May 23-27.

May 23-24 — One-hour programs about Madame Curie will be presented for Livermore High School Students, the community and Lab employees.

May 25 — Community Day

May 26 — Science Day at the Lab and the Livermore Chamber luncheon will feature a Lab speaker.

May 27 — Physics Day

June

A "Physics of Rodeo" lecture will be offered to the community, to coincide with Livermore's annual rodeo.

The Lab's "Scientist Drill Team" will perform in the Livermore Rodeo Parade.

June 25 — "Got Science" — a Saturday family event -will take place at the Lab's Discovery Center.

September/October

"Dr. Atomic" will premier at the San Francisco Opera and at the Livermore Valley Opera.

November

The Director's Distinguished Lecture Series will present a physics speaker.

National Ignition Facility broke ground. It is expected to be the world's most energetic laser when completed.

Though the Laboratory's core mission remains ensuring the safety and reliability of the nation's nuclear deterrent, the Laboratory contributes broadly to the nation's science and technology base. Weapons science and technology has found new applications that are helping the nation address new rapidly evolving national security threats and enhancing U.S. industrial competitiveness. The 1990s saw both the development of PEREGRINE, a new tool for helping doctors plan radiation treatment for cancer patients and Extreme Ultraviolet

Lithography (EUVL), developed in conjunction with Sandia, LBNL and industry to extend the current pace of semiconductor innovation.

As the Laboratory moves into the 21st century, emerging and ongoing research in prototype development and field-testing has allowed scientists to respond quickly to threats of biological, chemical and nuclear attacks.

Physics continues to play a core role in Laboratory business to explore beyond conventional nuclear weapons. That same science is now being applied not only to national security, but to detect cancer, develop new medical treatments, explore the solar system and discover new states of matter.

that lies at the heart of Einstein's 1905 explanation of Brownian motion.

Einstein's work on the interaction of light with matter, starting in 1905 with his explanation for the photoelectric effect based on light coming in quanta of energy, is integral to our understanding of lasers. Livermore's laser research program began in the 1970s, and the Lab has been at the forefront of field ever since, building ever-larger lasers for fusion and weapons research. Using lasers, LLNL produced the first evidence for laser-induced nuclear fission, and demonstrated the world's first X-ray laser. The saga continues with the National Ignition Facility (NIF), which will attain physics conditions found only in nuclear tests, and at the centers of stars. NIF will enable scientific discoveries in fields ranging from astrophysics to plasma physics to material science.

Physics has always played a key role in the scientific problems the Lab has addressed. Conversely, many of Livermore's most notable scientific achievements have been in physics, including the Nobel Prize awarded to Bob Laughlin for his explanation of the fractional quantum Hall effect. Other highlights include the discovery of metallic hydrogen in gas gun experiments led by physi-

cist Bill Nellis, the stringent tests of quantum electrodynamics provided by the Lab's unique Electron Beam Ion Trap (EBIT), the discovery of dark matter in the form of compact halo objects in our galaxy, and the explanation for the pulsations of a large class of variable stars. Just recently, the Lab's Web page noted that LLNL astrophysicists had discovered how the jets of material propelled from black holes trigger star formation, and the formation of galaxies.

Today, Livermore scientists are contributing their expertise and using science and technology that advances stockpile stewardship and homeland security to address many of the most important physics questions of the 21st century. What is the nature of the dark matter and energy that suffuse the universe while immune from direct observation? Where did the elements heavier than iron come from? Are there new states of matter at extreme temperature and density? What are the masses of the neutrinos? Did Einstein have the "last word" on gravity? As it happened a century ago, the answers will lead to new science and technology that will help us solve the problems of the century to come.